Thermoset and Thermoplastic foams for structural applications

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Contributions from
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N
PACIFIC OCEAN
CANADA
Location Map of TEXAS
PACIFIC OCEAN
Texas
ATLANTIC OCEAN
MEXICO
Gulf of Mexico
Map not to Scale


Denton
The Colony
Justin
Lewisville
Plano
Carrollton
Keller
Colleyville
75
Rowlett
North Richland Hills
Garland
Irving
Weatherford
Mesquite
820
Dallas
Fort Worth
Arlington
Edgecliff Village
20
DeSoto
Lancaster
171
Mansfield
Cedar Hill
Joshua
Ovilla
Ferris
Keene
Waxahachie
Palmer
34
144
Cleburne

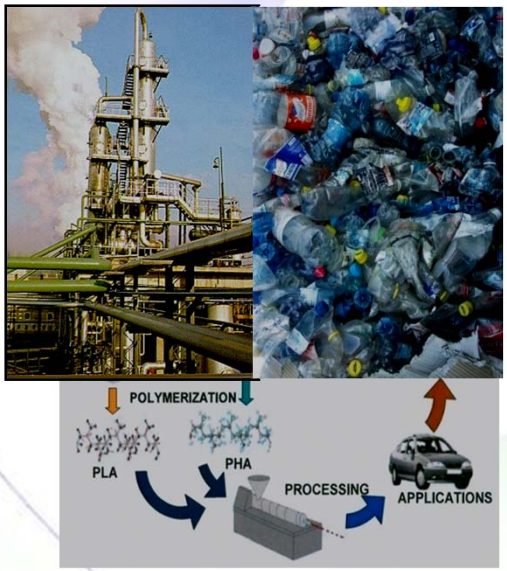


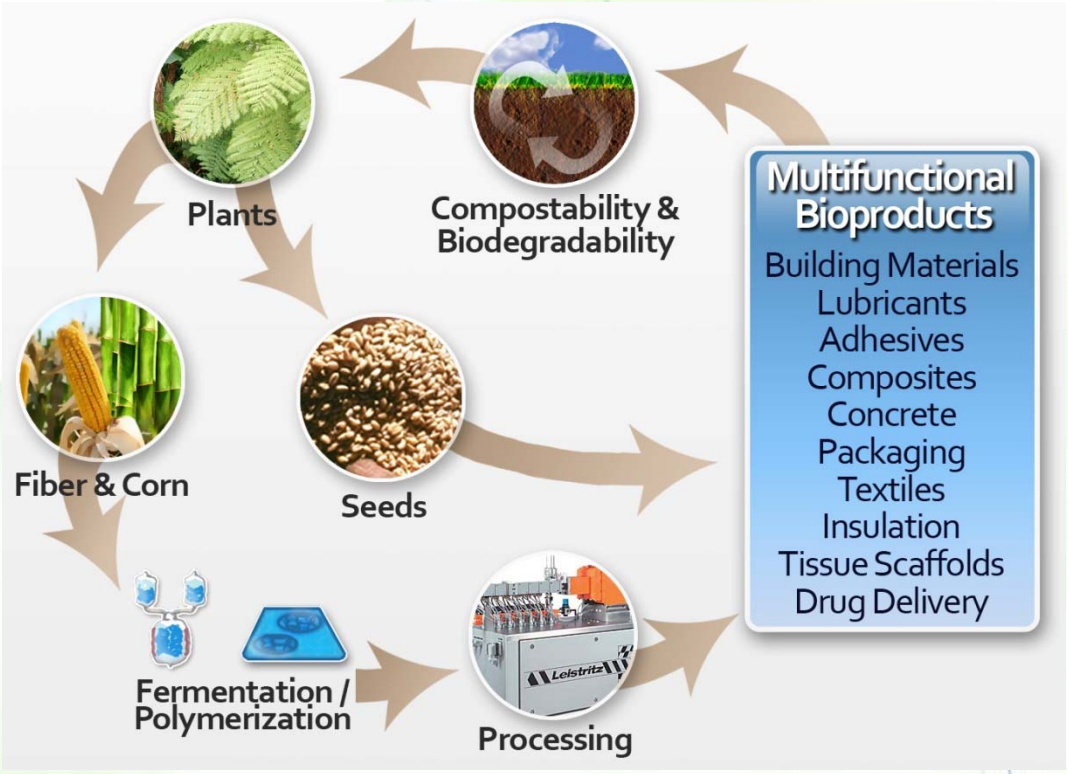
Discovery Park



- College of Engineering and College of Information Science
- Mechanical and Energy Engineering, Materials Science and Engineering, Electrical Engineering and Engineering Technology
- Center for Advanced Research and Technology ($20 million)
- Incubator for small business

Research and education: Integrated with industry







*By William McDonough & Michael Braungart

Mechanical/Materials Facilities

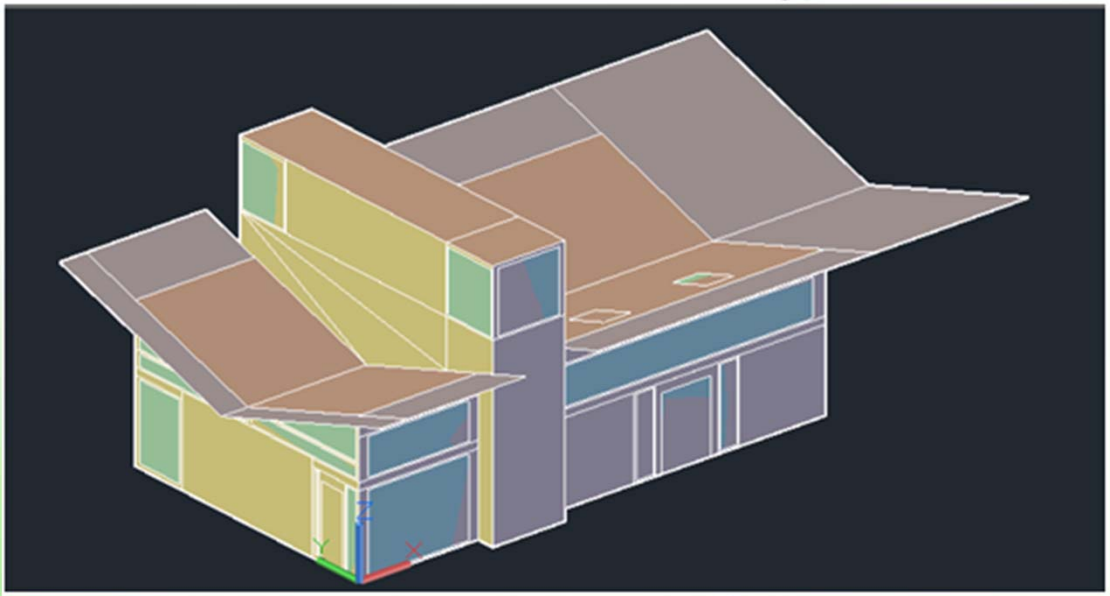






Energy Simulation





Prior work

Decreasing fiberglass consumption through natural renewable fillers

- Natural fiber based fillers are attractive.
- We utilize kenaf in our efforts





Kenaf



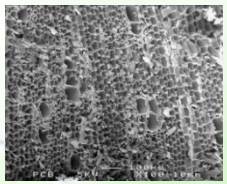


Bast fiber from the surface

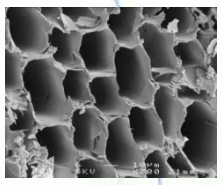


Glass fiber



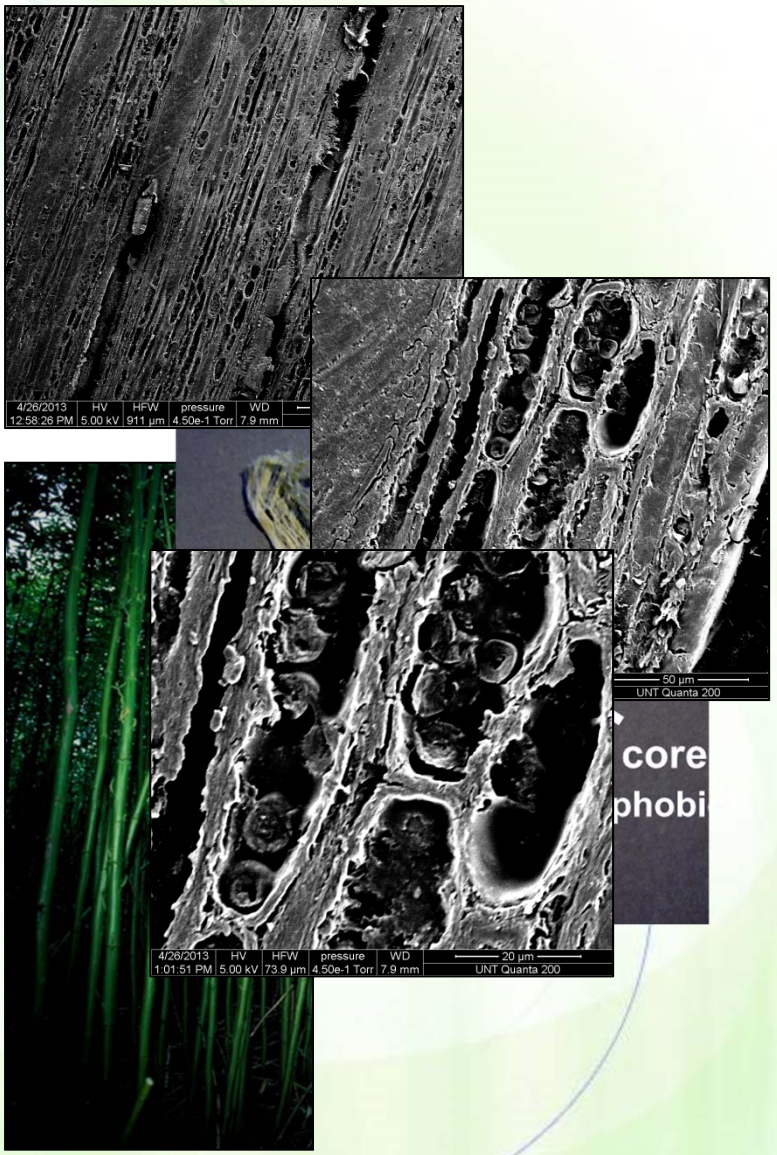




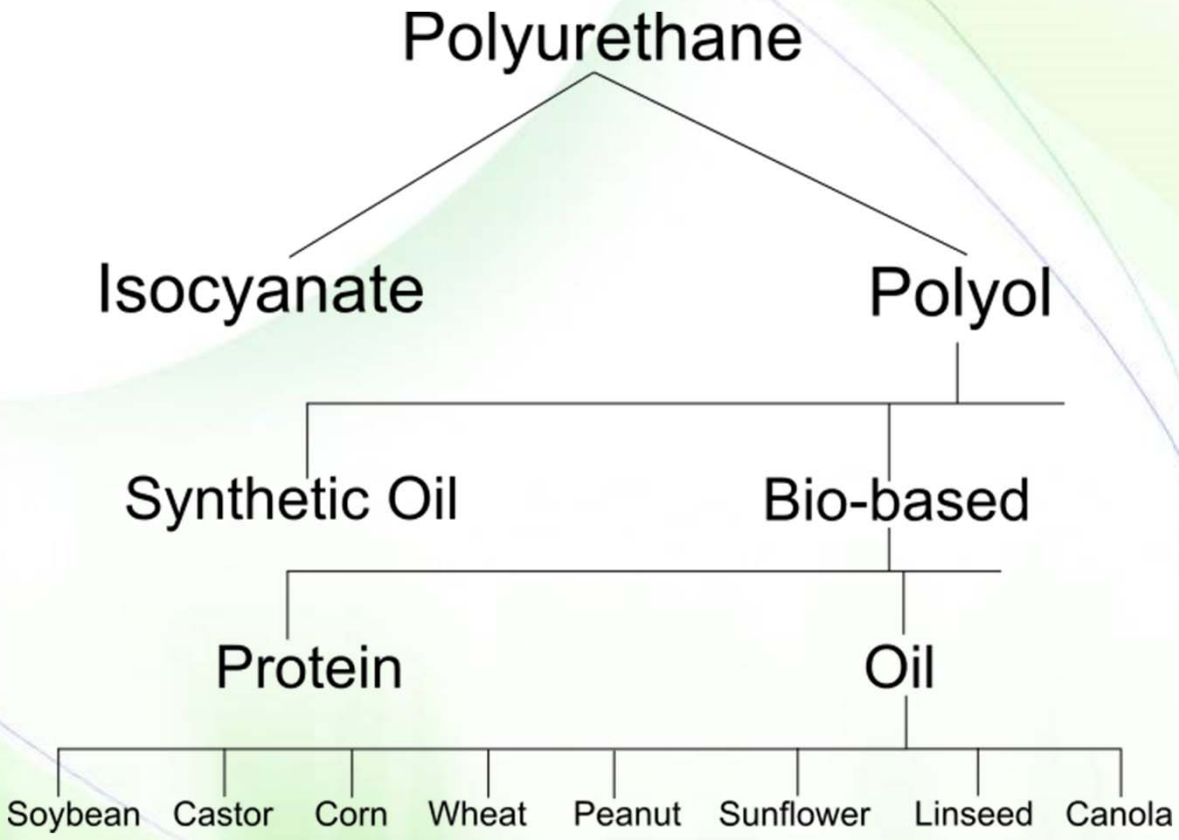


Kenaf core

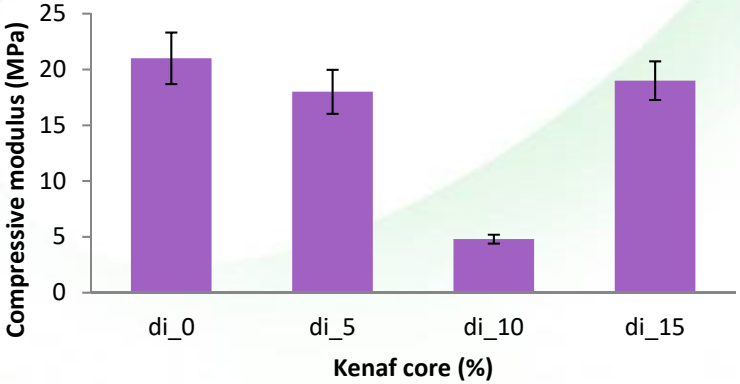
- The kenaf plant is branchless and grows up to an average height of 5.5 meters in 5 months.
- The stalk core, which is the woody core, can be used as a wood-product substitute and building material.
- Kenaf core particles are used to make panels with easy processing and with comparison to commercially available insulation panels.

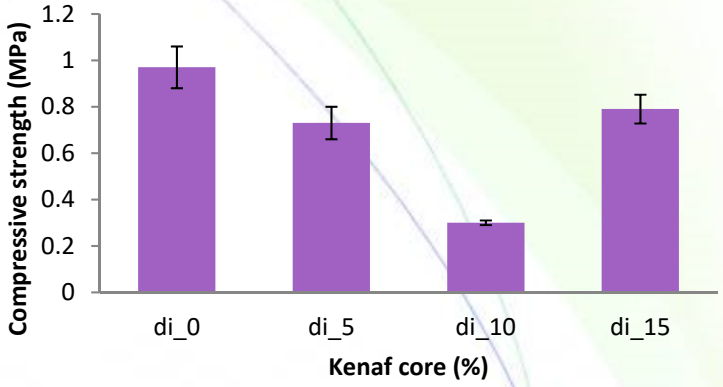


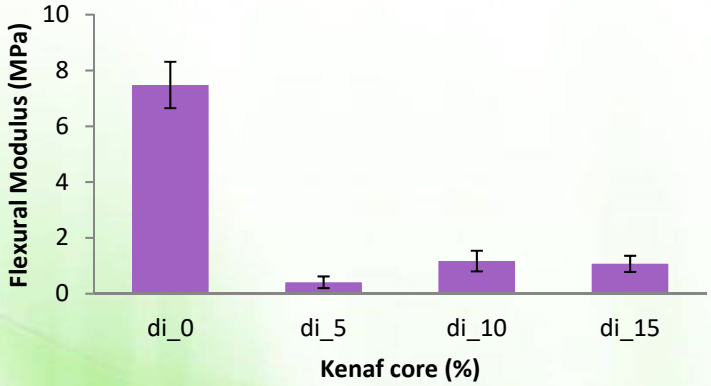
Polyurethane foam



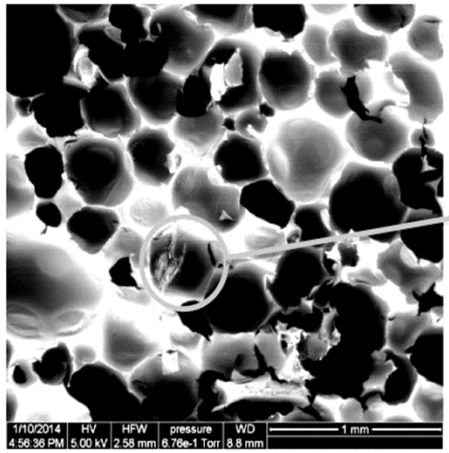
Mechanical properties for free expansion foam and foam composites

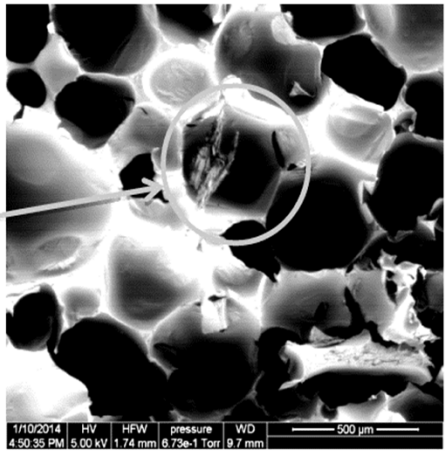


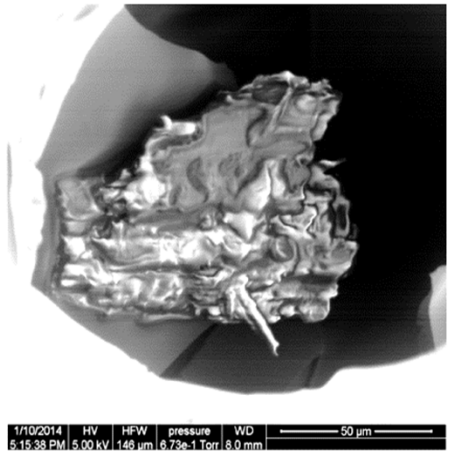


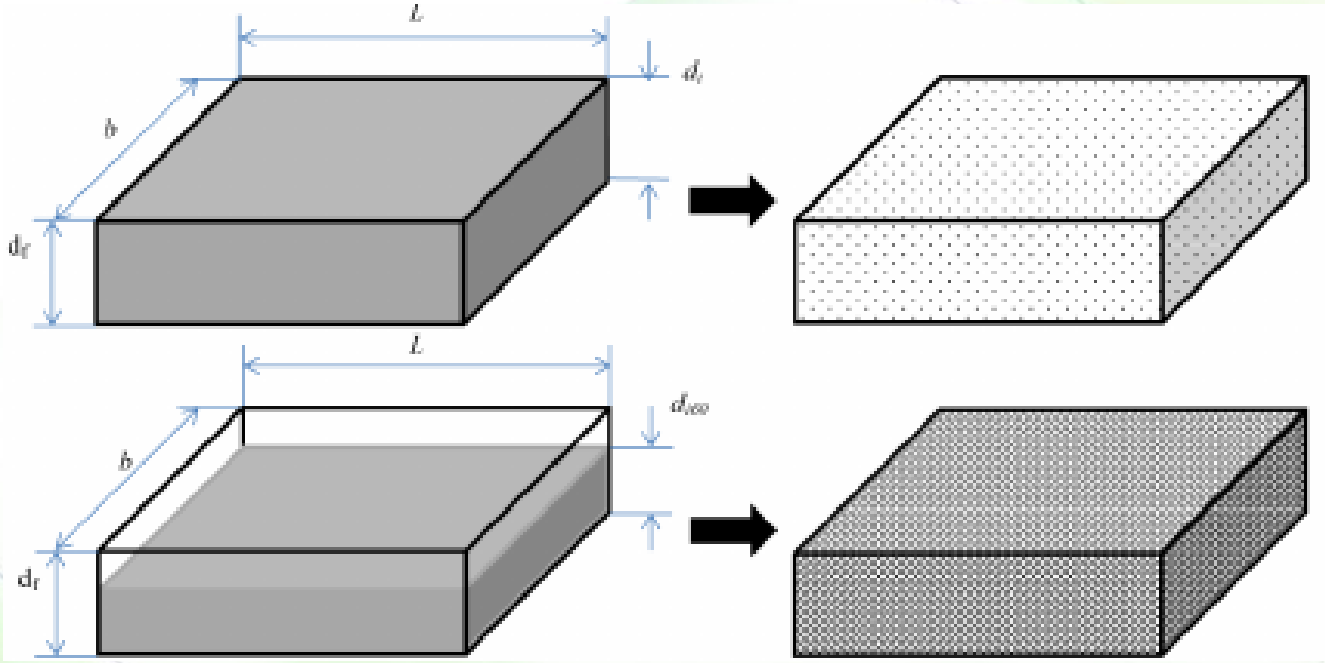


Why?

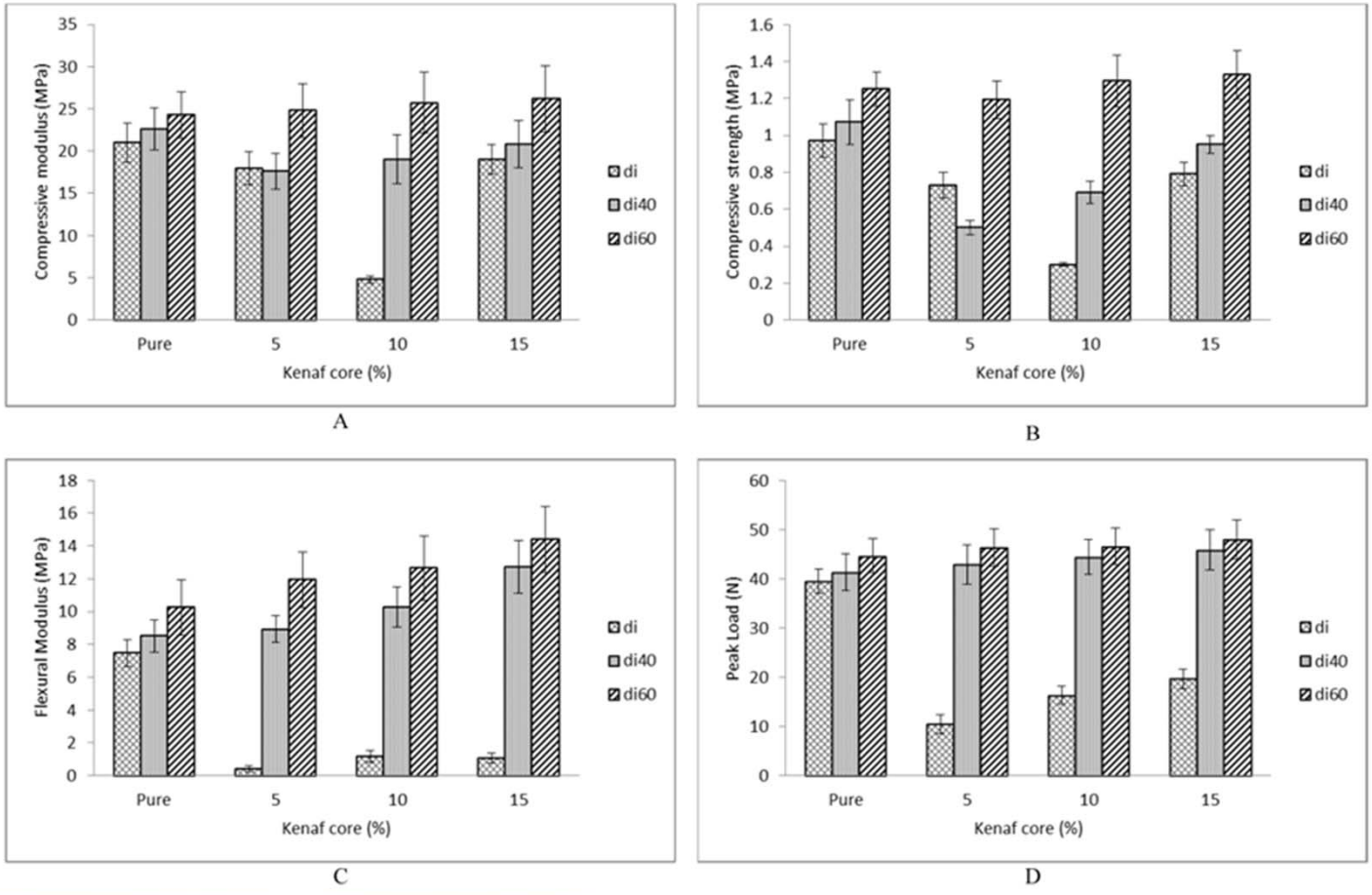

1/10/2014 | HV | HFW | pressure | WD
4:56:36 PM | 5.00 kV | 2.58 mm | 8.76e-1 Torr | 8.8 mm
1 mm
A


1/10/2014 | HV | HFW | pressure | WD
4:50:35 PM | 5.00 kV | 1.74 mm | 8.73e-1 Torr | 9.7 mm
500 µm
B


1/10/2014 | HV | HFW | pressure | WD
5:15:38 PM | 5.00 kV | 146 µm | 8.73e-1 Torr | 8.0 mm
50 µm
C

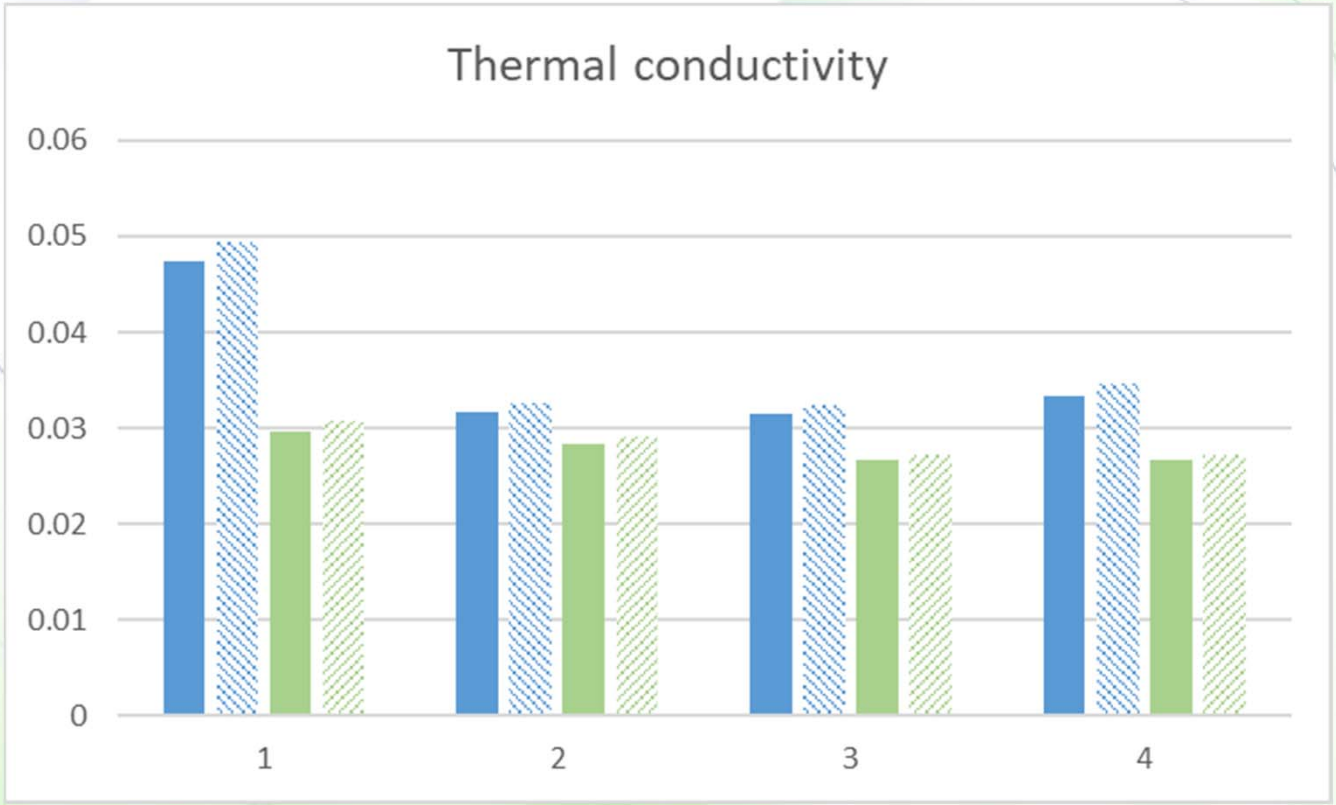

L
d_t
b
d_f
L
d_{eq}
b
d_f

Improved structural properties



(A) Compressive modulus, (B) compressive strength comparison (C) flexural modulus, and (D) peak load of rigid PU foam composites with increasing kenaf-core content of 5, 10, and 15 % and constraint volume expansion with d_{i40} and d_{i60}.

Thermal conductivity in rigid PU foams

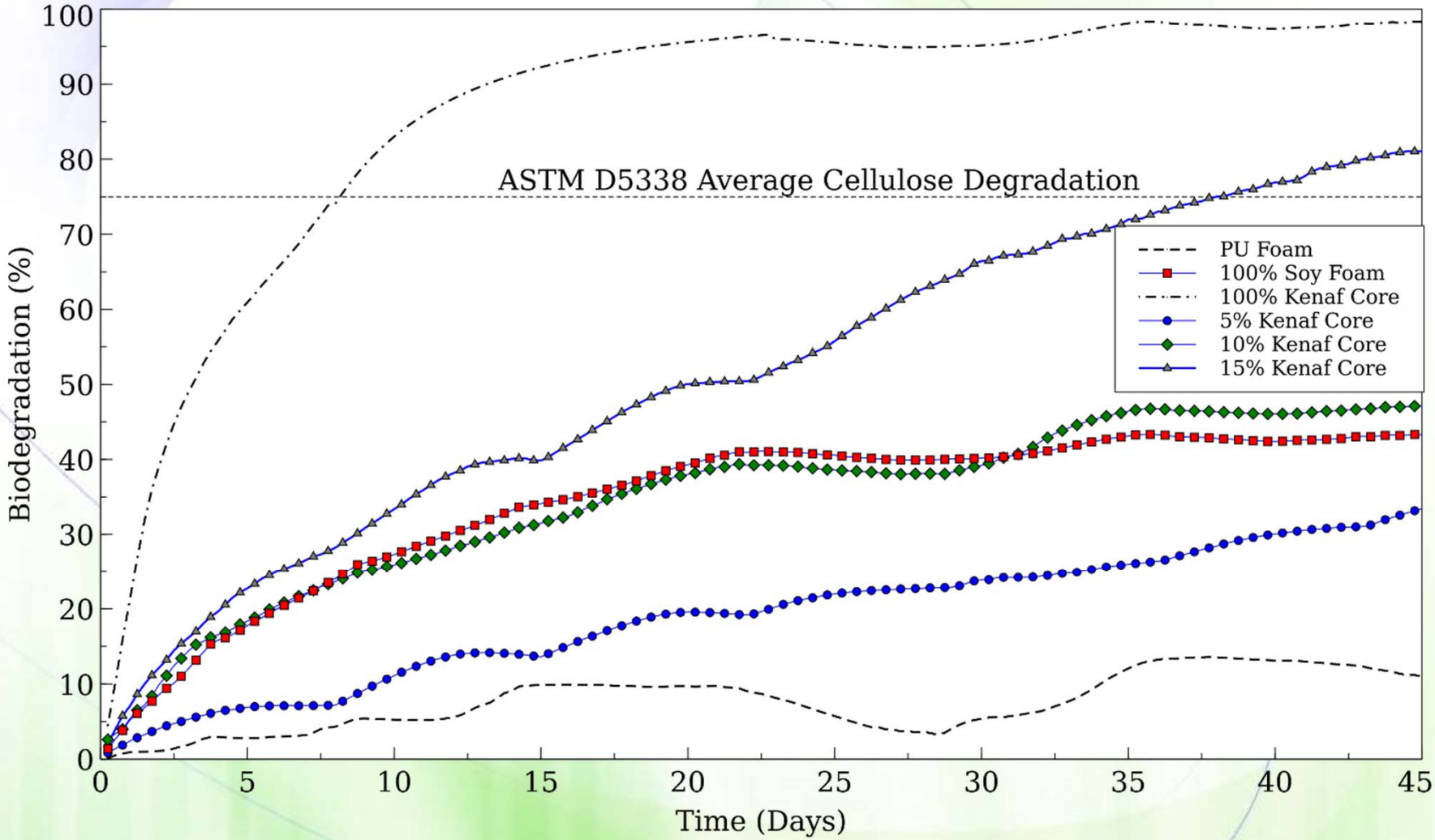


Inferences from PU + kenaf core

- A new manufacturing approach harnessing nucleation and bubble coalescence in rigid foaming resulted in improved mechanical and thermal properties

M. Nar, C. Webber III and N. A. D'Souza, Rigid polyurethane and kenaf core composite foams, Polym. Eng. Sci. 55, 132–144 (2015).

Bio-Soy polyurethane



Inferences

- The flexible soy foam benefitted from the new manufacturing approach causing bubble coalescence
- The kenaf core did not improve properties for mechanical or thermal conductivity over the soy foam by itself
- The use of kenaf core together with soy foams promoted compostability

Poly lactic acid foams

Manufacturing process



Control of cellular architecture and morphology



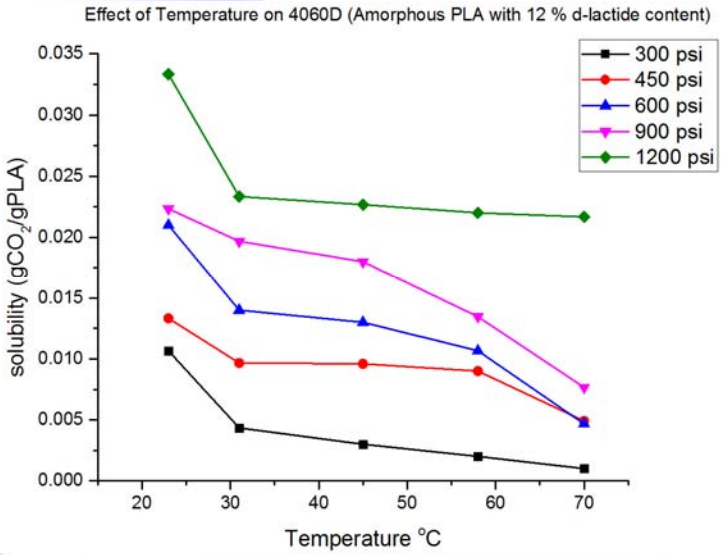
Optimum thermal, sound absorption insulation

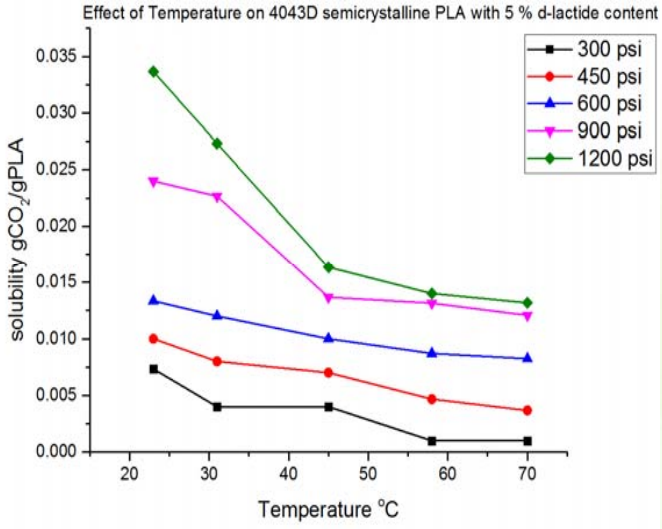


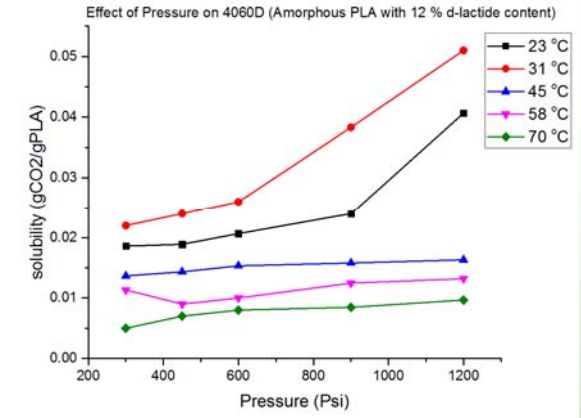
Improved thermal, sound insulation performance

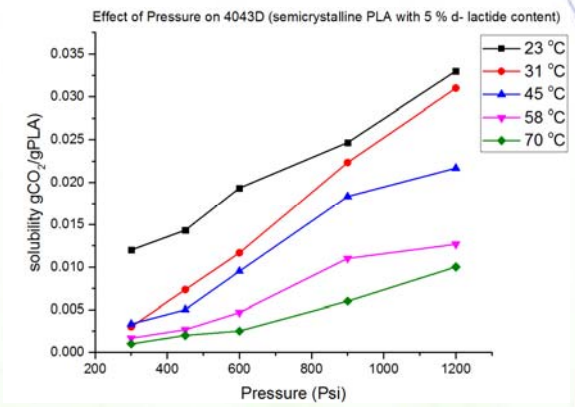


Energy savings + Greener environment + Improved air quality + lower health risks.

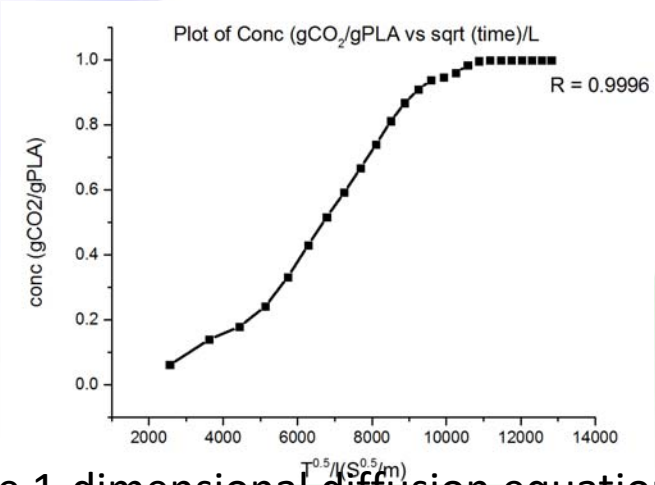








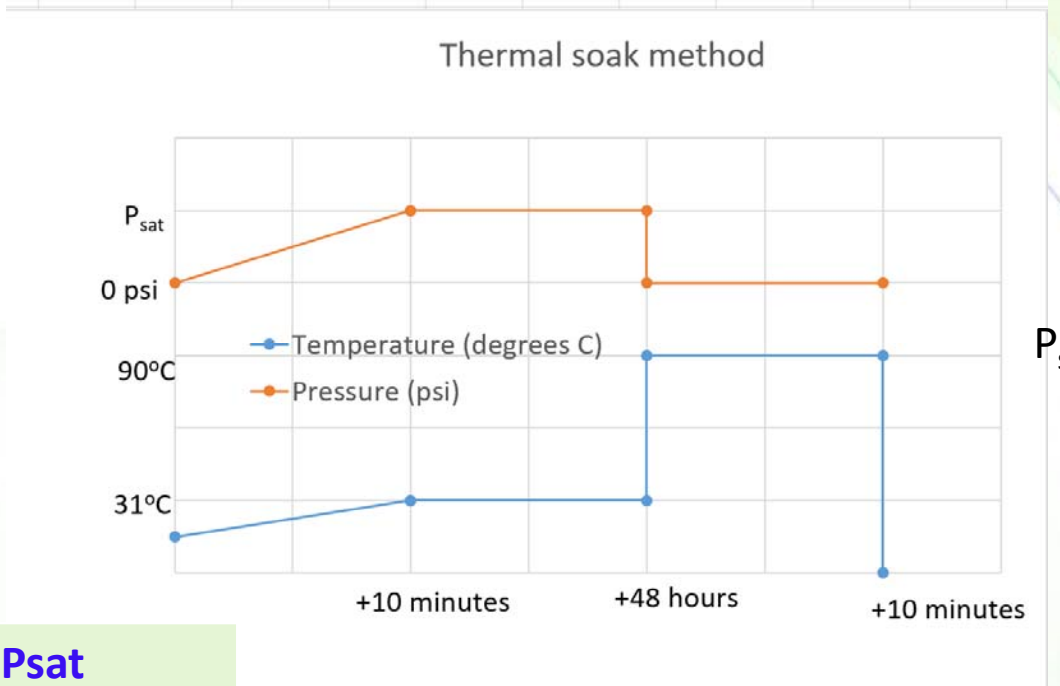
- Solubility for amorphous PLA was from 0.001 wt% (300 psi) to 0.05 wt% (1200 psi), and the solubility for semicrystalline PLA was from 0.001 wt% (300 psi) to 0.034 wt% (1200 psi).



The 1-dimensional diffusion equation was used to compute the diffusion data [46].

This yielded diffusion coefficient of CO_2 in the amorphous PLA grade at 70 ^oC as $\mathbf{7.86*10^{-9}\ \frac{m^2}{s}}$.

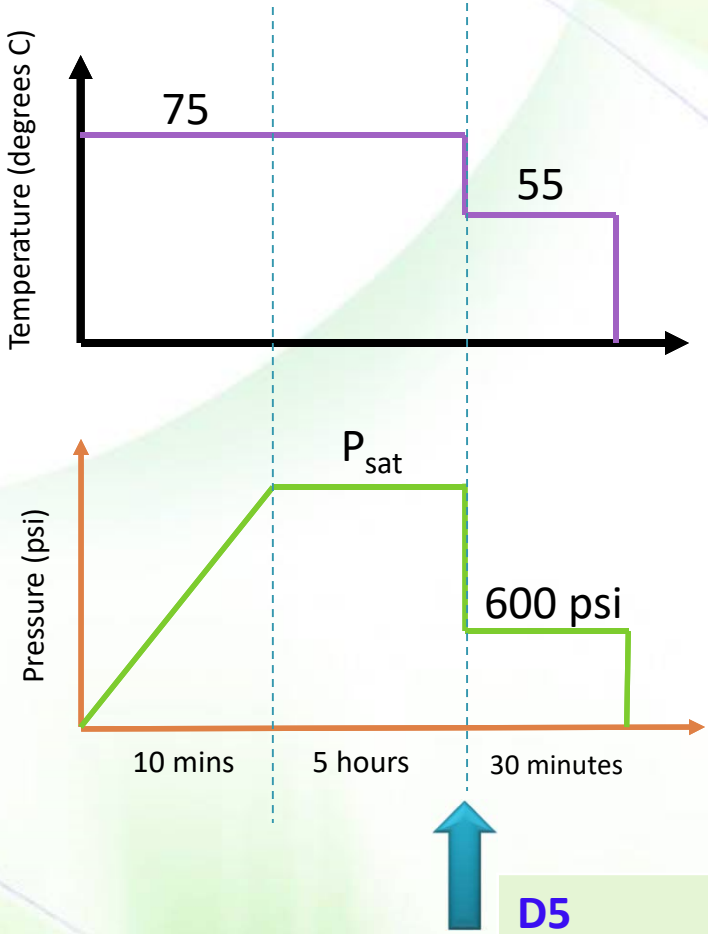
Manufacturing approach-1



P_{sat} = (600, 650, 700) psi

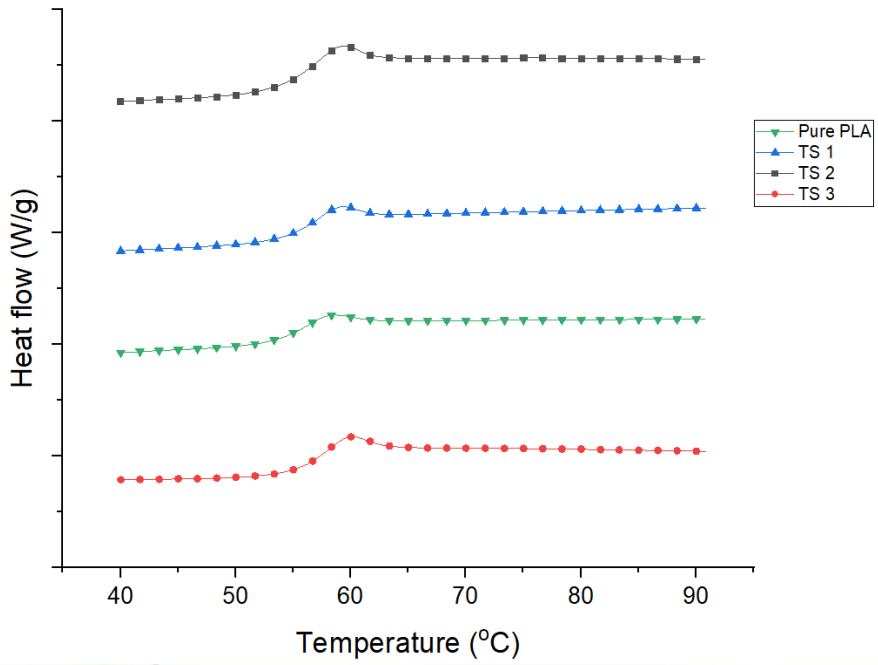
Name	Psat
TS1	600
TS2	650
TS3	700

Manufacturing approach-2

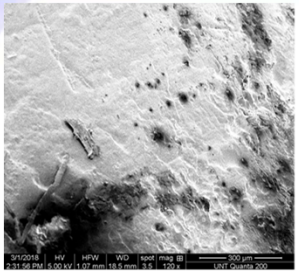


D1	**1400**
D2	1500
D3	1600
D4	1750

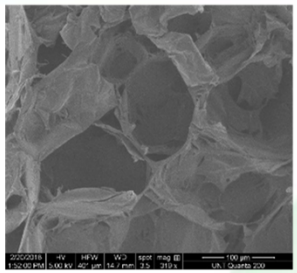
D5	**1400**
D6	1450
D7	1500



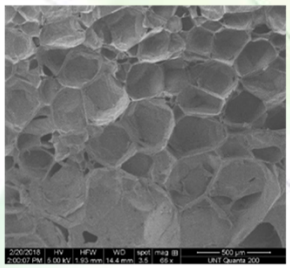
Foam Type	First Cycle Tg (°C)	Second Cycle Tg (°C)
TS 1	57.16	56.88
TS 2	57.81	58.44
TS 3	58.4	59.19
D1	55.24	55.37
D2	57.78	58.35
D3	58.28	58.68
D4	58.51	59.16
D5	58.43	58.32
D6	58.67	58.59
D7	59.28	58.98



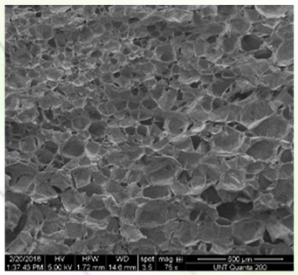
PLA_0



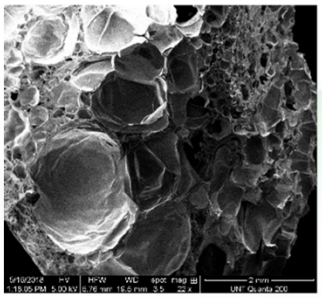
T.S 1



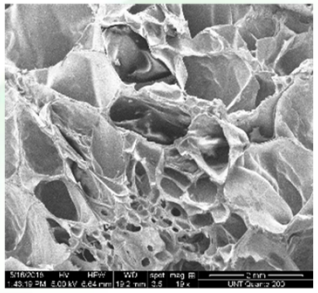
T.S 2



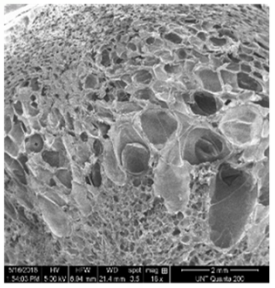
T.S 3



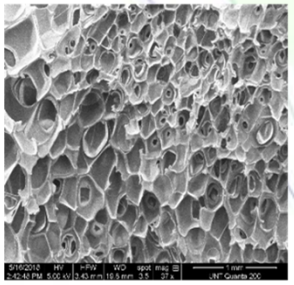
D1



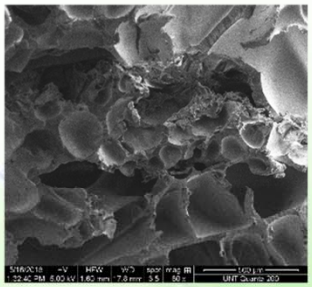
D2



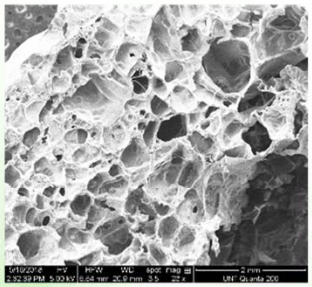
D3



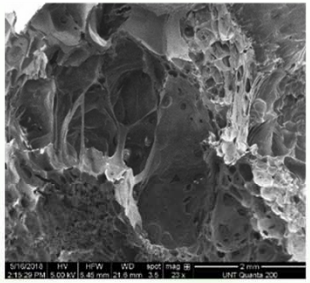
D4



D5

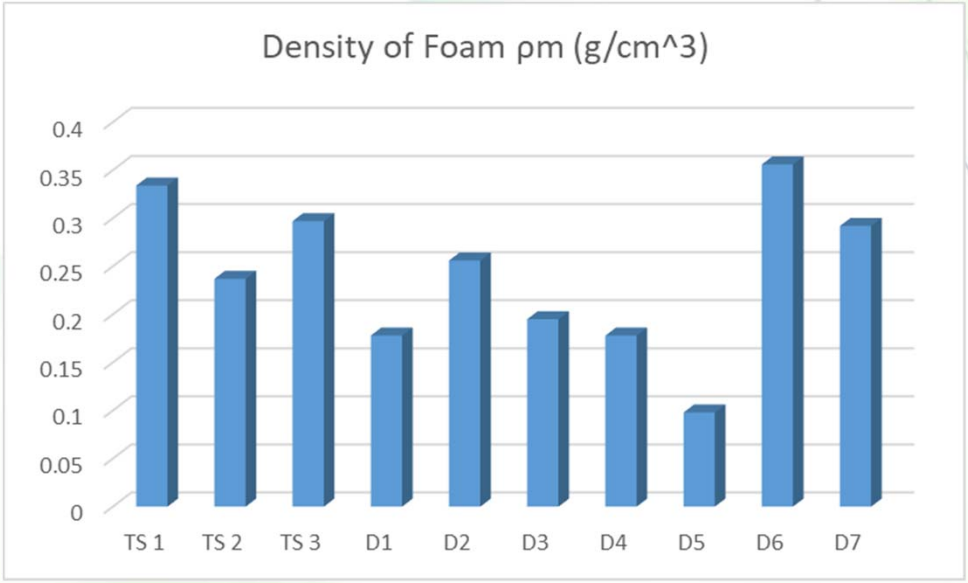


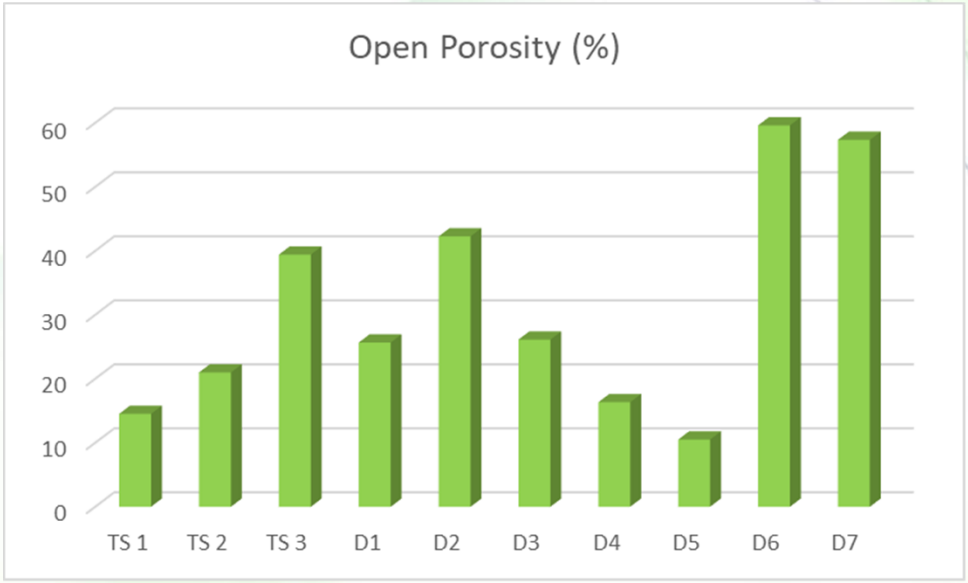
D6

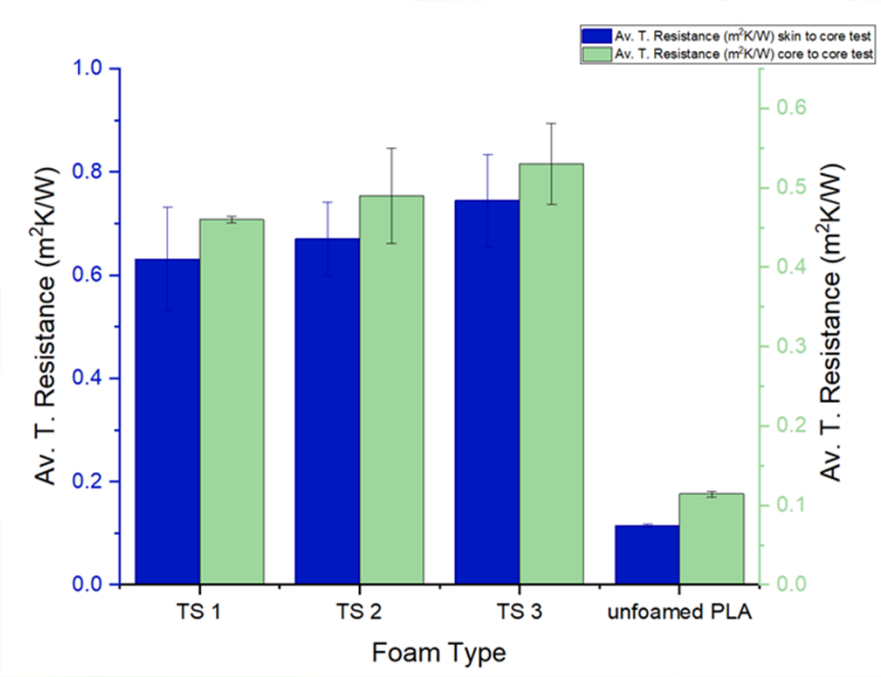


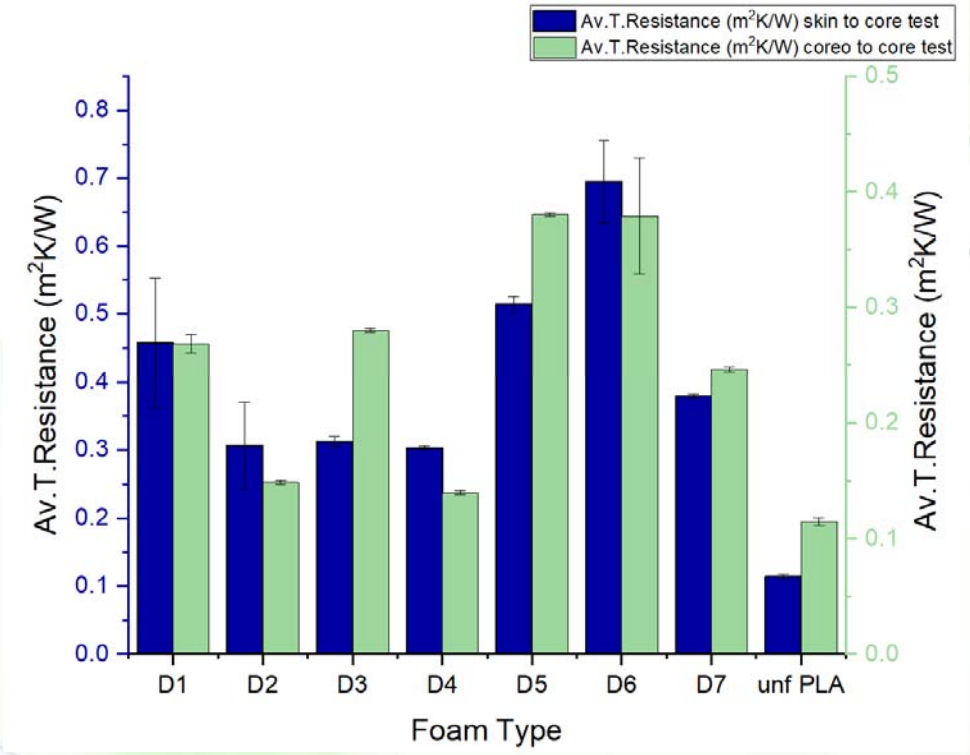
D7

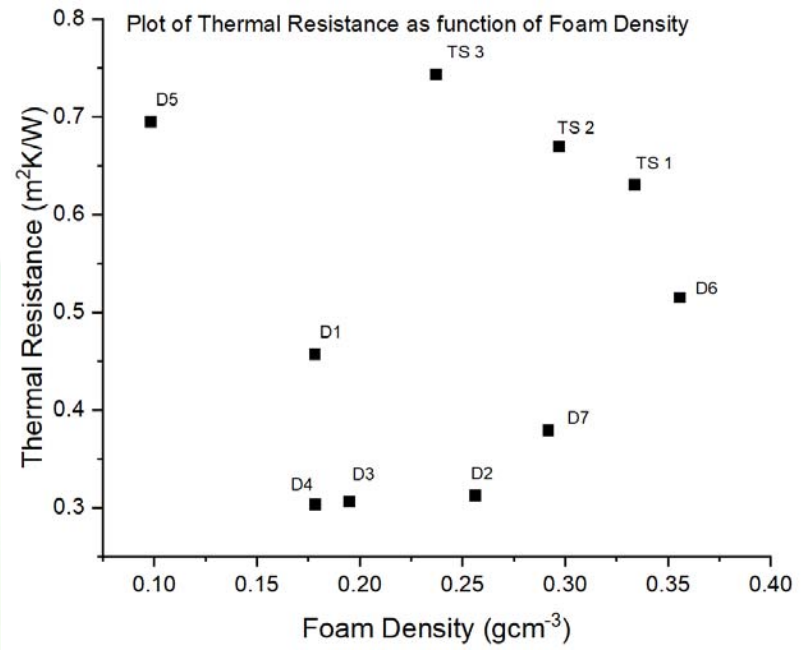
Density of foams

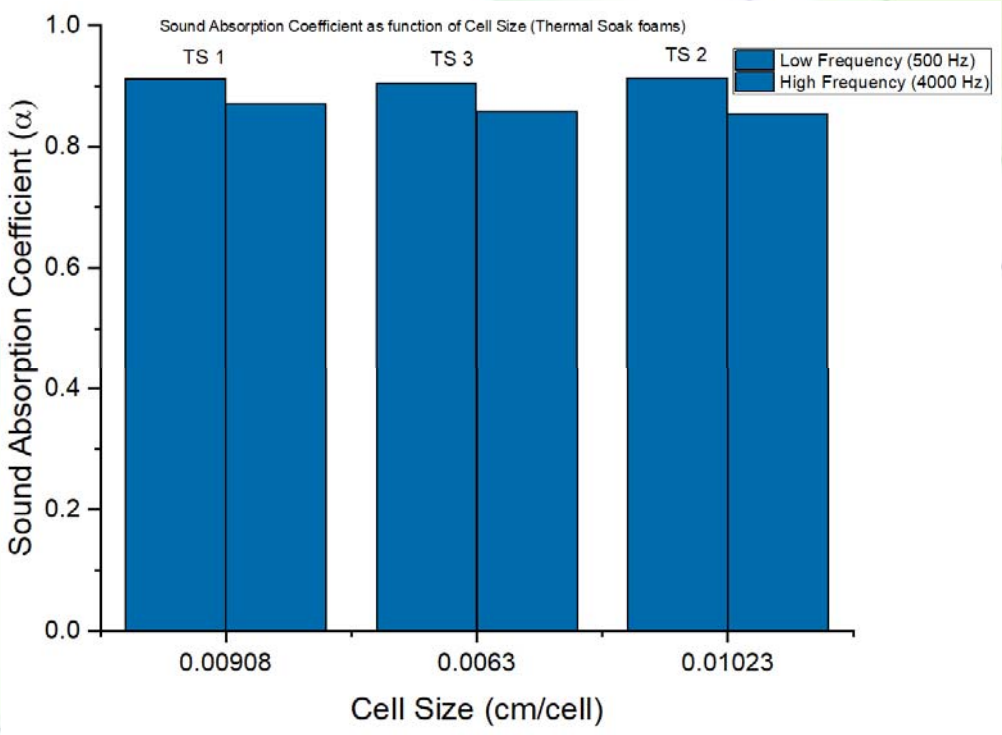


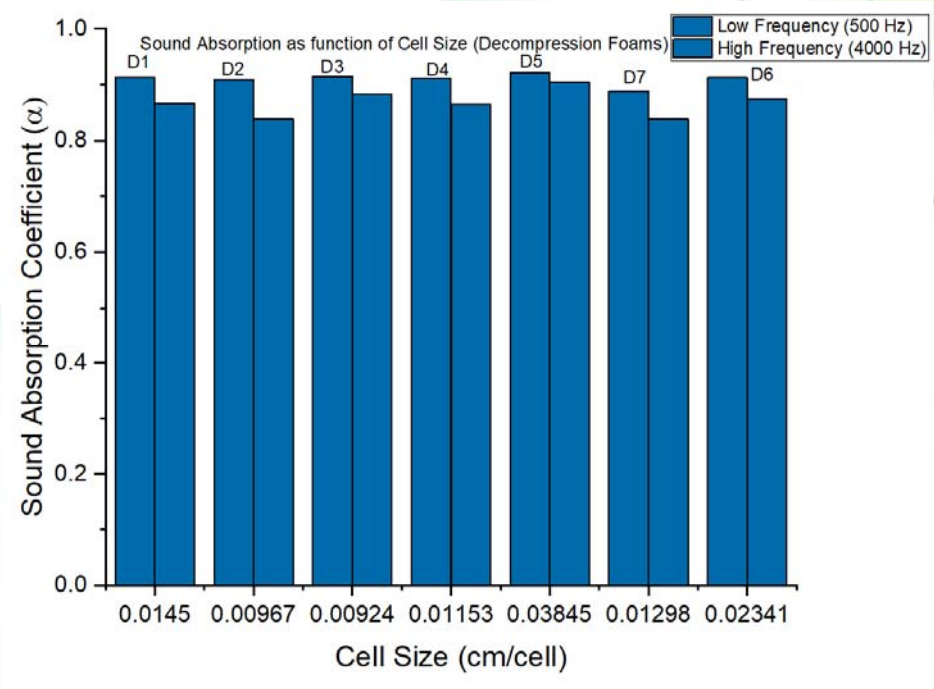

Open Porosity (%)
60
50
40
30
20
10
0
TS 1
TS 2
TS 3
D1
D2
D3
D4
D5
D6
D7


Av. T. Resistance (m²K/W) skin to core test
Av. T. Resistance (m²K/W) core to core test
Av. T. Resistance (m²K/W)
1.0
0.8
0.6
0.4
0.2
0.0
0.6
0.5
0.4
0.3
0.2
0.1
0.0
TS 1
TS 2
TS 3
unfoamed PLA
Foam Type

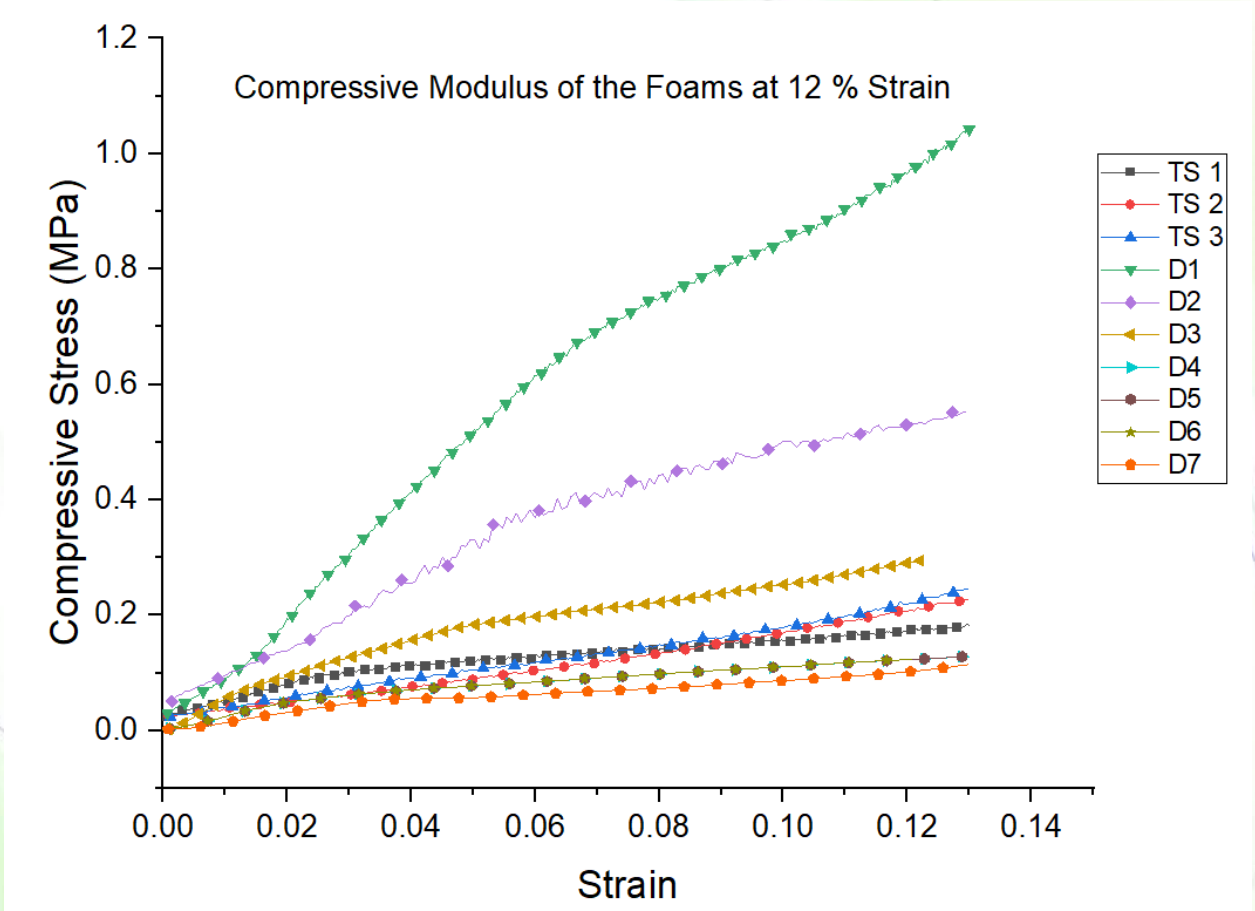

Av.T.Resistance (m²K/W) skin to core test
Av.T.Resistance (m²K/W) coreo to core test
Av.T.Resistance (m²K/W)
Av.T.Resistance (m²K/W)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.0
0.1
0.2
0.3
0.4
0.5
D1
D2
D3
D4
D5
D6
D7
unf PLA
Foam Type

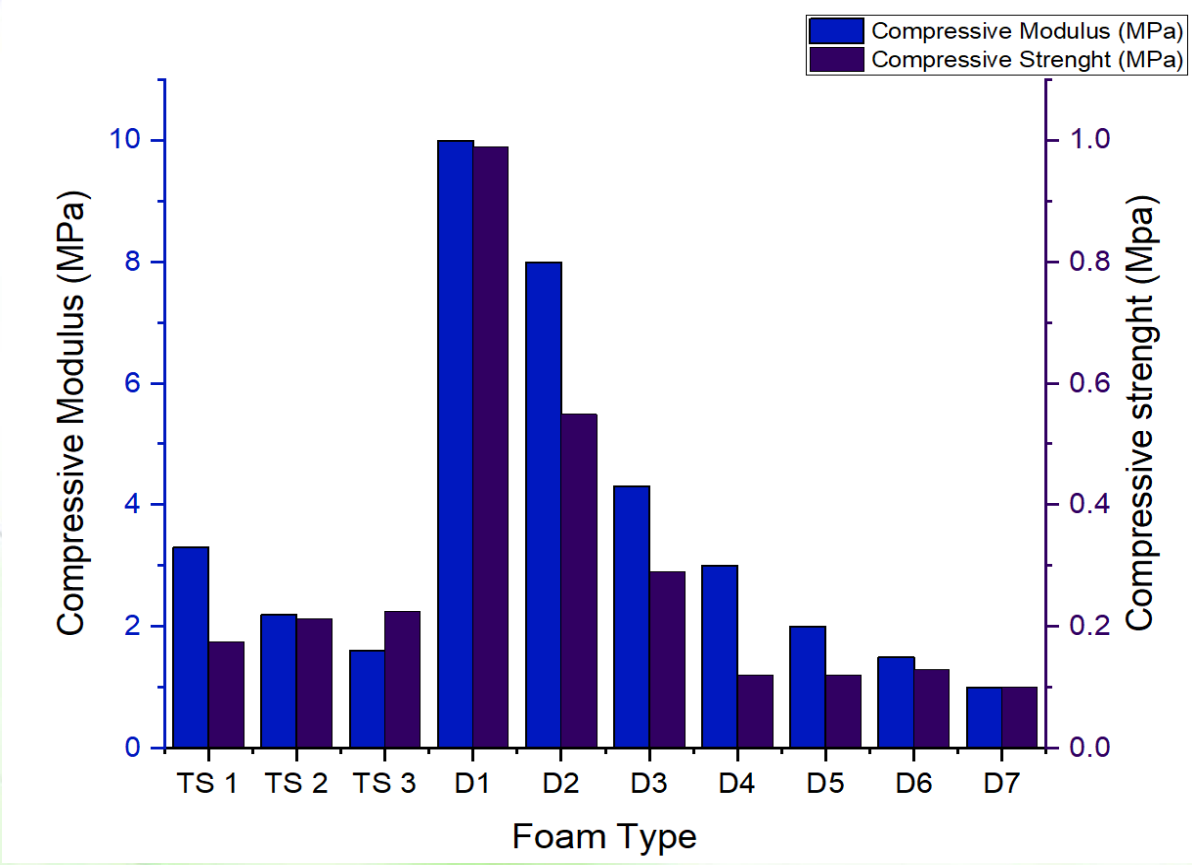

Plot of Thermal Resistance as function of Foam Density
Thermal Resistance (m^2K/W)
Foam Density (gcm^{-3})
0.8
0.7
0.6
0.5
0.4
0.3
0.10
0.15
0.20
0.25
0.30
0.35
0.40
TS 3
TS 2
TS 1
D5
D6
D1
D7
D4
D3
D2


Sound Absorption Coefficient as function of Cell Size (Thermal Soak foams)
TS 1
TS 3
TS 2
Low Frequency (500 Hz)
High Frequency (4000 Hz)
Sound Absorption Coefficient (α)
1.0
0.8
0.6
0.4
0.2
0.0
0.00908
0.0063
0.01023
Cell Size (cm/cell)


Sound Absorption as function of Cell Size (Decompression Foams)
Low Frequency (500 Hz)
High Frequency (4000 Hz)
D1
D2
D3
D4
D5
D7
D6
Sound Absorption Coefficient (α)
1.0
0.8
0.6
0.4
0.2
0.0
0.0145
0.00967
0.00924
0.01153
0.03845
0.01298
0.02341
Cell Size (cm/cell)

Compression Testing




Compressive Modulus (MPa)
Compressive Strenght (MPa)
Compressive Modulus (MPa)
Compressive strenght (Mpa)
0
2
4
6
8
10
0.0
0.2
0.4
0.6
0.8
1.0
TS 1
TS 2
TS 3
D1
D2
D3
D4
D5
D6
D7
Foam Type

Summary

- Reactive thermoset foams
  - Rigid foams with kenaf core
    - The foams did not get reinforced until bubble coalescence was induced through constrained foaming
    - Mechanical and thermal properties improved
  - Flexible polyurethane foams
    - No improvement from constrained foaming (bubble coalescence to mechanical properties
    - No improvement to thermal resistance
  - Using kenaf core increased the compostability of the foams

Summary

- Thermoplastic PLA
  - Thermoplastics that are physically foamed have a complex stages of dissolution, bubble growth, coalescence. The thermoplastic foams are further impacted by the exit stages of CO2
  - The impact of the processing methods on thermal conductivity or sound absorption is not significant

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